Chapter 20

Geophysics

One goal of hydrogeologists is to understand the subsurface. In other words, to have a good idea about the types and thicknesses of rocks beneath land surface, the depth to water, the direction of ground-water flow, and how the geology affects ground-water storage and movement.

Hydrogeologists often rely on geologic information obtained from drilling wells, outcrops of the bedrock at various locations, stream channels that cut into the land surface, and road cuts for highways and railroads to provide clues as to the subsurface geology. But, these sources of information usually are sparse. Scientists often need to speculate and theorize about geology between well sites and other exposures.

One way to gather information when physical access to the subsurface is not available is to use geophysical methods. These methods give a glimpse of what lies below the surface without actually drilling into the ground and collecting geologic samples. It is similar to how doctors use x-rays and ultrasounds to see what is inside a body without actually operating. Considering the cost of drilling, geophysics, which is usually quick and less expensive, becomes a really attractive tool for helping hydrogeologists.

As the name implies, geophysics is the study of the physics of the Earth and its surrounding atmosphere. Geophysical techniques are used to detect discontinuities in the Earth, where one area or region differs significantly from another in some property. Identifying discontinuities can help hydrogeologists locate changes in the geology, where ground water occurs, and even buried features and objects below the Earth's surface.

A number of geophysical methods exists and each has advantages. In the broadest sense, these methods can be grouped into solid earth geophysics, which deals with earthquakes and understanding the dynamics of the Earth, and applied (exploration) geophysics, which consists of methods used to explore the Earth; these are discussed in this chapter.

Applied geophysics is grouped into various fields such as gravimetry, magnetic, electrical, electromagnetic, seismic, and radioactivity. All of these techniques can be used from the air, on the ground, or in boreholes.

Gravitational surveys are useful for identifying changes over large areas. The mass of rocks affects the value of the acceleration of gravity. Therefore, as mass changes, so will the gravity measurements. This is useful because rocks such as granite and gneiss have larger gravity values than unconsolidated sediments, such as sand and gravel. By measuring changes in gravity, changes from one type of geology to another can be mapped. This information also can help map buried features, such as large igneous rock bodies, channels filled with sediments, or caverns in limestone.

Magnetic surveys measure differences in the Earth's magnetic field caused by magnetic materials in the Earth's crust. Because sedimentary rocks, such as limestone and shale, generally are not magnetic, using magnetic surveys can help hydrogeologists detect the depth to the magnetic basement rocks. Also, in some areas, basalts (volcanic rocks which may be aquifers in some places) may have magnetic minerals, whereas the surrounding sediments and rocks possibly are nonmagnetic. Therefore, magnetic surveys can help identify the extent of the basalt, and therefore the extent of the aquifer. In eastern Nevada, magnetic surveys have been used to help identify the locations of igneous intrusions into the carbonate rocks.

Electrical methods consist of sending electric current into the ground and measuring the conductance and resistance in the Earth materials. This method is often used in borehole surveys, where probes are lowered down boreholes and changes in the electrical properties are measured along a vertical profile. Changes in the rock type, density, and fluid properties, such as salinity and temperature, can result in variations in the electric signal.

Electromagnetic (EM) surveys involve sending short electromagnetic waves into the Earth and measuring the time of return. Usually, this method is mobile, where the sending and receiving units are mounted on a vehicle and can be driven across an area of interest or lowered into a borehole. EM has been very useful in identifying intrusions and buried channels in the shallow subsurface, as well as mapping shallow bedrock geology. From the surface, most EM techniques do not penetrate to large depths, so the method has limitations for deep systems such as in the Basin and Range of Nevada.

A geophysical method that has been used a lot recently is temporal or microgravity. Microgravity measures very small changes in gravity directly beneath the instrument. As mentioned earlier, gravity can be affected by the mass of the geologic units. Likewise, the change in ground-water storage in an aquifer can affect the gravity. Therefore, by measuring the microgravity over time in numerous locations over an aquifer that is being pumped, changes in storage in the aquifer (declines or rises in the amount of water in storage) can be measured. This is useful in identifying where aquifers are affected by pumpage and in determining aquifer characteristics such as specific yield and porosity.

Seismic reflection and refraction methods use a system where either a hammer on a metal plate on the surface or small explosive charges are set off, which send seismic waves into the subsurface. On the Earth's surface, numerous stations with geophones (detectors to measure the energy waves) are set up at various distances from the explosive charge. The time it takes for the seismic waves to return from the subsurface, where they are reflected or refracted off of different geologic layers, can tell scientists the depth of the geologic layers and the type of materials the waves are passing through (the speed of the waves will vary depending on the geologic material or density). Likewise, the pattern of the waves and when and where the waves return to the surface (distance from the explosive charge) also will be affected by the depth of the layers and the type of geology that is refracting the waves. These techniques are used frequently in the oil industry to detect stratigraphic traps where oil is found.

Radioactive methods involve both the measurement of natural radiation and the induction of radiation from an energy source to gather information about the geology. Most commonly used methods involve lowering a geophysical tool down into a borehole and measuring how signals change between different geologic layers. Passive methods, which measure existing radiation, include measuring natural gamma and other radioactive emissions from geologic materials. Nonpassive methods involve the application of a radioactive energy source (such as gamma-gamma and neutron emissions) and the measurement of how this energy is either backscattered or moves through the surrounding rocks.

Tomography is another borehole geophysical method that is useful when two drill holes are in proximity of each other. At various depth increments, an energy source, such as seismic or radar, can be lowered down one hole and the signal measured at various depths in the other hole. This gives a really good profile of the entire geologic sequence that occurs between the two holes.

One interesting use of geophysics is to identify buried tanks and drums, and to outline the extent of contaminant plumes, all which have aided in the clean-up efforts of contaminated sites. Another use has been in forensic geology, where geophysics has been used to help locate buried bodies and disturbed geology. This technology has been used to identify buried bunkers in wartime and has helped to find hidden combatants and elusive leaders.

Many other geophysical methods are used on a regular basis but are not mentioned in this chapter. The main point is that geophysics provides a valuable tool for understanding the subsurface of the Earth without having to drill numerous holes. Like all tools in geology, geophysics by itself is useful but has its limitations. To truly understand a geologic or hydrologic system, it is best to have a variety of tools, such as boreholes, field mapping, geochemistry, and geophysics, which either support the conclusions of each other or possibly identify where additional study is needed.